

APPLICATION
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TITLE: TRANSFORMATIONS BETWEEN COMBINED AND
INDIVIDUAL WORKFLOWS

APPLICANTS: KARSTEN SCHULZ AND MARIA E. ORLOWSKA

Fish & Richardson P.C.
1425 K Street, N.W.
11th Floor
Washington, DC 20005-3500
Tel.: (202) 783-5070
Fax: (202) 783-2331

ATTORNEY DOCKET:
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Transformations Between Combined and Individual Workflows

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority to U.S. Provisional Application Serial No. 60/399,455, filed on July 31, 2002, and titled FLEXIBLE WORKFLOW MANAGEMENT IN CROSS-ORGANIZATIONAL ENVIRONMENTS.

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TECHNICAL FIELD

This description relates to workflow management systems.

BACKGROUND

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Conventional workflow systems exist which allow enterprises to formalize the processes by which the enterprises achieve their business objectives. Such workflow systems provide step-by-step descriptions of tasks which must or should be performed as part of the workflow, so that individuals or groups within the enterprise can be assigned individual (or groups of) tasks. The tasks may be dependent upon one another; for example, a task may only be begun upon completion of a prior task(s), or tasks may be included in iterative task loops. Additionally, the tasks may have more complex dependencies, requiring application of extensive logic rules to ensure proper completion of the workflow.

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Examples of such conventional workflows can be found explicitly or implicitly in almost any enterprise. For example, a manufacturing plant may have a workflow for producing a particular type of good. As another example, an organization selling goods may have a workflow for obtaining the goods, inputting orders and/or payments for the goods, selecting a shipper for shipping the goods, and updating an inventory record based on the sale.

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Given that individual enterprises often have and use their individual workflow(s) as just described, it may be problematic for one enterprise to interact with another enterprise, while still maintaining the use of their respective workflows as part of the interaction(s). For example, a workflow associated with a first enterprise may have its own nomenclature and/or semantics, which may be incompatible with the workflow of a second enterprise. This is particularly true, given that such workflows are often formulated completely independently of one another. Another difficulty facing enterprises desiring to work together is that workflows are often private

or confidential in nature, and the business(es) may be hesitant to share some or all of their private workflows with an external party.

As a result of these and other difficulties associated with sharing workflows between enterprises, collaborations between enterprises are often limited. For example, the enterprises may only be able to interact in relatively simplistic manners, so that interactions between the enterprises are limited in quantity and complexity. As another example, the enterprises may have to resort to formulating a new workflow to describe some or all of the tasks that are to be performed as part of the enterprises' collaboration.

SUMMARY

According to one general aspect, a combined workflow is built. a first workflow comprising a first plurality of tasks and associated with a first party is accepted, a second workflow comprising a second plurality of tasks and associated with a second party is accepted, the first plurality of tasks and the second plurality of tasks are ordered into a combined workflow having a task order that, when executed, provides a desired result of a business collaboration between the first party and the second party, and ordering tasks are added that are operable to implement the order of the combined workflow and thereby achieve the desired result.

Implementations may include one or more of the following features. For example, in adding ordering tasks, a sequential flow may be formed which interleaves implementation of the first plurality of tasks and the second plurality of tasks, or a parallel flow of a first task within the first plurality of tasks and a second task within the second plurality of tasks may be formed, or at least one of a conjunctive splitting and joining tasks which specify the task order may be added.

Also in adding ordering tasks, at least one of alternative splitting and joining tasks may be added which specify the task order, or a first splitting task may be added which designates that a first task within the first workflow is followed by a first following task and a second following task. In the latter case, the first following task may be added as a second task within the second workflow, or the first following task may be added as a first joining task, the first joining task designating a second task within the second workflow as following the first joining task and the first splitting task.

In the latter case, a second splitting task may be added following the second task within the second workflow, the second splitting task designating that the second task is followed by a

third following task and a fourth following task. In this case, the third following task may be added as the second following task, the second following task being a second joining task within the first workflow that designates that a third task within the first workflow follows the second following task. Further in adding ordering tasks, the fourth following task may be added as a third joining task within the second workflow, the third joining task designating that a fourth task within the second workflow follows the third joining task and the third task within the first workflow. Still further, the second ordering task may be a joining task which designates a fourth task within the second workflow, the fourth task following the second task within the combined workflow.

In adding ordering tasks, a third task within the first workflow may be added as the second following task, and a second joining task may be added within the first workflow as the third following task, the second joining task designating that a fourth task within the first workflow follows the third following task.

Ordering the first plurality of tasks may include inputting the task order from an operator, in which case, adding ordering tasks may include representing the first workflow as a first matrix in which the first plurality of tasks are each represented as first vertices, where values of the first vertices within the first matrix are determined by first dependencies between the first plurality of tasks, and representing the second workflow as a second matrix wherein each of the second plurality of tasks are represented as second vertices, where values of the second vertices within the second matrix are determined by second dependencies between the second plurality of tasks. In the latter case, adding ordering tasks may include inserting the first matrix and the second matrix into a third matrix, modifying a selected value within the third matrix, thereby reflecting a construction or removal of a selected dependency between two vertices within the first plurality of tasks, consistent with the task order, adding a fourth vertex before a first of the two vertices, the fourth vertex having a first chosen value reflecting a first new dependency between the fourth vertex and the first of the two vertices, and adding a fifth vertex after the first of the two vertices, the fifth vertex having a second chosen value reflecting a second new dependency between the fifth vertex and the first of the two vertices.

The first workflow may be an abstracted workflow associated with a first actual workflow of the first party, and further wherein a confidential nature of the first actual workflow may be protected by use of the abstracted workflow in constructing the combined workflow.

Also, a subset of the combined workflow may be selected for execution by the first party. In this case, it may be determined that the subset includes a third plurality of tasks, each consecutive pair of the third plurality of tasks connected by a dependency, or that a last task within the third plurality of tasks precedes at most one subsequent task within the combined workflow. In the latter case, it may be determined that no internal task within the third plurality of tasks, exclusive of the last task, immediately precedes an external task that is not included within the third plurality of tasks, or that no internal task within the third plurality of tasks, exclusive of a first task of the third plurality of tasks, immediately succeeds an external task that is not included within the third plurality of tasks.

According to another general aspect, an apparatus includes a storage medium having instructions stored thereon. The instructions include a first code segment for accepting a first workflow comprising a first plurality of tasks and associated with a first party, a second code segment for accepting a second workflow comprising a second plurality of tasks and associated with a second party, a third code segment for accepting a task order for forming the first plurality of tasks and the second plurality of tasks into a combined workflow, wherein the combined workflow, when executed, provides a desired result of a business collaboration between the first party and the second party, and a fourth code segment for adding ordering tasks operable to implement the order of the combined workflow and thereby achieve the desired result.

Implementations may include one or more of the following features. For example, the fourth code segment may include a fifth code segment for forming a sequential flow which interleaves implementation of the first plurality of tasks and the second plurality of tasks, or a fifth code segment for forming a parallel flow of a first task within the first plurality of tasks and a second task within the second plurality of tasks.

The fourth code segment may include a fifth code segment for adding at least one of conjunctive splitting and joining tasks which specify the task order, or for adding at least one of alternative splitting and joining tasks which specify the task order.

The third code segment may include a fifth code segment for inputting the task order from an operator. In this case, the fourth code segment may include a fifth code segment for representing the first workflow as a first matrix in which the first plurality of tasks are each represented as first vertices, where values of the first vertices within the first matrix are determined by first dependencies between the first plurality of tasks, and a sixth code segment

for representing the second workflow as a second matrix wherein each of the second plurality of tasks are represented as second vertices, where values of the second vertices within the second matrix are determined by second dependencies between the second plurality of tasks.

Further in this case, the fourth code segment may include a seventh code segment for
5 inserting the first matrix and the second matrix into a third matrix, an eighth code segment for modifying a selected value within the third matrix, thereby reflecting a construction or removal of a selected dependency between two vertices within the first plurality of tasks, consistent with the task order, a ninth code segment for adding a fourth vertex before a first of the two vertices, the fourth vertex having a first chosen value reflecting a first new dependency between the fourth
10 vertex and the first of the two vertices, and a tenth code segment for adding a fifth vertex after the first of the two vertices, the fifth vertex having a second chosen value reflecting a second new dependency between the fifth vertex and the first of the two vertices.

The first workflow may be an abstracted workflow associated with a first actual workflow of the first party, and further wherein a confidential nature of the first actual workflow
15 may be protected by use of the abstracted workflow in constructing the combined workflow.

The apparatus may include a fifth code segment for selecting a subset of the combined workflow for execution by the first party. In this case, the fifth code segment may include a sixth code segment for determining that the subset includes a third plurality of tasks, each consecutive pair of the third plurality of tasks connected by a dependency. Alternatively, the
20 fifth code segment may include a sixth code segment for determining that a last task within the third plurality of tasks precedes at most one subsequent task within the combined workflow.

In the latter case, the sixth code segment may include a seventh code segment for determining that no internal task within the third plurality of tasks, exclusive of the last task, immediately precedes an external task that is not included within the third plurality of tasks, or
25 for determining that no internal task within the third plurality of tasks, exclusive of a first task of the third plurality of tasks, immediately succeeds an external task that is not included within the third plurality of tasks.

The details of one or more implementations are set forth in the accompanying drawings and the description below. Other features will be apparent from the description and drawings,
30 and from the claims.

DESCRIPTION OF DRAWINGS

FIG. 1 is an illustration of a three-tiered workflow model.

FIG. 2 is an illustration of an example of the three-tiered workflow model of FIG. 1 for implementing a manufacturing process.

FIG. 3 is an illustration of a more generic example of the three-tiered workflow model of FIG. 2.

FIG. 4 is a diagram of an architecture for implementing a three-tier workflow model.

FIG. 5 is a Petri-Net representation of state and event information related to a workflow task.

FIG. 6 is a Petri-Net representation illustrating state and event information for two successive tasks in a workflow, relative to their workflow view task.

FIG. 7 is a Petri-Net representation illustrating state and event information for a workflow view task in a workflow view, relative to its private tasks.

FIG. 8 is a block diagram of a task illustrating the task inputs and outputs types of relevant data.

FIG. 9 is a block diagram of an eService.

FIG. 10 is a diagram illustrating operations for modifying one or more workflows.

FIG. 11 is a digraph representing a workflow.

FIG. 12 is an illustration of a matrix used as a specialization operator.

FIG. 13 is a matrix illustrating an algorithm for computing specialization.

FIG. 14 is an illustration of a matrix used as a generalization operator.

FIG. 15 is a matrix illustrating an algorithm for computing generalization.

FIG. 16 is an illustration of a matrix used as a verticalization operator.

FIG. 17 is a block diagram illustrating a classification scheme for classifying workflow groups.

FIGS. 18-23 provide further examples of how a workflow can be verticalized (generalized).

FIG. 24 is a flowchart describing an algorithm to compute v-structures.

FIG. 25 is a flowchart for finding valid v-structures.

FIG. 26 is a flowchart for finding v-structures which is a back-up to the flowchart of FIG. 25.

FIG. 27A is a first example of a digraph (workflow) 2700.

FIG. 27B is a table listing adjacent v-structures for each vertex (node) of the digraph of FIG. 27A.

FIG. 28A is a first example of a digraph (workflow).

5 FIG. 28B is a table listing adjacent v-structures for each vertex (node) of the digraph of FIG. 28A.

FIG. 29 is a first screenshot of a tool for identifying v-structures.

FIG. 30 is a second screenshot of a tool for identifying v-structures.

FIG. 31 is a third screenshot of a tool for identifying v-structures.

10 FIG. 32 is a fourth screenshot of a tool for identifying v-structures.

FIG. 33 is a block diagram of an outsourced workflow.

FIG. 34 is a block diagram of a distributed workflow.

FIG. 35 is an expanded block diagram of the distributed workflow.

FIG. 36 is a block diagram of a parallel combination of multiple workflows.

15 FIG. 37 is a combination workflow including synchronizing tasks.

FIG. 38 is an example of a first matrix resulting from a first expansion operation.

FIG. 39 is an example of a second matrix resulting from a second expansion operation.

FIG. 40 is an example of a third matrix resulting from a third expansion operation.

FIG. 41 is an example of a fourth matrix resulting from a fourth expansion operation.

20 FIGS. 42A-42D are digraphs illustrating valid and invalid results of a reduction operation.

FIG. 43 is a matrix that is an example of a reduction operator.

FIG. 44 is a block diagram of three aspects of workflow interoperability.

FIG. 45 is a block diagram of a corporate procurement process (CPP).

25 FIG. 46 is a block diagram of a collaborative workflow.

FIG. 47 is a block diagram of a workflow management system.

FIG. 48 is an illustration of a more generic example of the three-tiered workflow model of FIG. 2.

FIG. 49 is an illustration of an aggregate workflow.

30 FIG. 50 is a flowchart illustrating techniques for changing a state of a task within a workflow.

FIG. 51 is a flowchart illustrating techniques for changing a state of a workflow view task within a workflow view.

FIG. 52 is a flowchart for aggregating a workflow view and a workflow into an aggregated workflow.

5 FIG. 53 is a flowchart for inserting aggregation routing tasks into the aggregate workflow of FIG. 52.

DETAILED DESCRIPTION

In the following description, Section I describes a three-level model for allowing enterprises to fully and easily collaborate with one another, while still taking advantage of the enterprises' individual, existing workflows and ensuring confidentiality of tasks within the workflows on an as-needed basis. The three-level or three-tier model involves, on the first level, a first private workflow associated with a first enterprise, and a second private workflow associated with a second enterprise. On the second level, each of the private workflows is abstracted, such that a first virtual workflow having a first set of virtual tasks is generated which corresponds to the first private workflow, while a second virtual workflow having a second set of virtual tasks is generated which corresponds to the second private workflow. Finally, at the third level, a collaboration workflow is generated from the two virtual workflows. The virtual workflows have state dependencies with respect to their respective private workflows, such that a completion of a virtual task definitively corresponds to a completion of a corresponding actual task(s) within the private workflow.

Section II describes techniques for determining whether an abstraction level of a workflow can be legitimately altered in a desired manner, and for, if allowed, actually performing the alteration. For example, a private task or group of tasks within an enterprise's existing workflow may be abstracted, or generalized, into one or more virtual tasks. Conversely, a virtual task may have its abstraction level reduced, or specialized, into one or more private tasks. These techniques for determining a feasibility of altering an abstraction level of a workflow, and for performing the alterations, can be utilized for various purposes, including implementation of the three-tier collaborative workflow model described in Section I.

Section III describes techniques for combining, or expanding, multiple workflows into a single workflow, while maintaining a validity of both the individual and joined workflows.

Conversely, techniques are also described for dividing, or reducing, a single workflow into a plurality of individual workflows, where the individual workflows may be performed by individual parties or enterprises. These techniques can be used for a variety of purposes, including implementation of the three-tier workflow model of Section I.

5 Section IV describes why the three-tier model is necessary and/or useful for performing collaborative workflows, along with examples of such collaborative workflows.

 Section V describes techniques for executing the three-tier model within, or in association with, a workflow engine. More specifically, Section V describes techniques for effectively supporting concurrent execution of an actual workflow and its associated workflow
10 view.

Section I

FIG. 1 is an illustration of a three-tiered workflow model 100. In FIG. 1, a first tier of the three-tiered workflow model is a partner or private tier 102. Private tier 102 includes a first
15 private workflow 104 associated with a first entity such as an enterprise, a second private workflow 106 associated with a second entity, and a third private workflow 108 associated with a third entity. In FIG. 1, each workflow (e.g., 104, 106, 108) includes various tasks having various dependencies therebetween, and each of the tasks represents an actual task to be performed by, for example, an employee of the appropriate entity.

20 A second tier of the three-tiered workflow model is an abstracted or virtual or “workflow view” tier 110. Workflow view tier 110 includes abstracted versions of the private workflows 104, 106, and 108. More particularly, the workflow view tier 110 includes a workflow view 112 abstracted from the private workflow 104, another workflow view 114 abstracted from the private workflow 106, another workflow view 116 that is also abstracted from the private
25 workflow 106, and a final workflow view 118 which is abstracted from private workflow 108. As explained in more detail below, a given private workflow may have a plurality of abstractions or workflow views which can be generated therefrom, as shown by the example of workflow views 114 and 116, which, although different, are both generated from the same private
30 workflow 106. This allows different partners to have different views of the same underlying workflow.

 Specific techniques for generating the abstracted workflow views 112, 114, 116, and 118

(and for (re-)obtaining the private or partner workflows 104, 106, and 108 therefrom) are discussed in more detail in Section II. For the purposes of this section, however, it is assumed only that the workflow views are generated by some technique, which may be fully or partially automated, or may be simply performed by trial-and-error.

5 The third tier of the workflow model of FIG. 1 includes a coalition workflow tier 120. The coalition workflow tier 120 includes, in FIG. 1, two coalition workflows which represent the combination of particular workflow views. More specifically, the coalition workflow tier 120 includes a first coalition workflow 122 (also identified as “Coalition B” in FIG. 1) which represents a combination of the workflow view 112 and the workflow view 114. Similarly, the
10 coalition workflow tier 120 also includes another coalition workflow 124 (also identified as “Coalition A” in FIG. 1), which represents a combination of the workflow views 116 and 118.

 Specific techniques for combining the various workflow views into their corresponding coalition workflows (and for (re-)obtaining the individual workflow views from the coalition workflows) are discussed below in Section III. For the purposes of this Section, however, it is
15 assumed only that the coalition workflows are generated by some technique, which may be fully or partially automated, or which may merely include trial-and-error.

 The three-tiered approach of FIG. 1 is essentially a logical integration of all data and workflows needed by an application into one logical workflow management system, which may also be referred to as the “unified approach.” It implies the existence of a unified meta-model
20 which is able to map different existing models. Such integration creates the illusion of a single workflow management system, and hides from the user and the application the intricacies of different workflow management systems and different access methods. It provides users and applications with uniform access to workflows contained in various workflow management systems without migrating the workflows to a new workflow management system, without
25 requiring the users and applications to know either the location or the characteristics of different workflow management systems.

 FIG. 2 is an illustration of an example of the three-tiered workflow model of FIG. 1 for implementing a manufacturing process. In FIG. 2, a company B 202 confirms their upcoming production of a good with a company A 204. Company B 202 is responsible to produce a
30 particular set of widgets (widgets 1, 2, 3, and 4) that are required in a production process of company A 204. Company B 202 has an internal (or private or partner) workflow K 206, which

corresponds in concept to one of the partner workflows 104, 106, or 108 of FIG. 1. The partner workflow K 206 has a corresponding workflow view L 208, which corresponds in concept to one of the workflow views 112, 114, 116, or 118 of FIG. 1. Similarly, an internal workflow O 210 of company A 204 is abstracted as a workflow view P 212.

5 In the production process of FIG. 2, then, a collaboration of workflow view L 208 and workflow view P 212 provide a collaboration workflow corresponding in concept to coalition workflows 122 and 124 of FIG. 1. In FIG. 2, this collaboration occurs in a peer-to-peer manner, and the coalition workflow is not explicitly shown as a separate workflow, as discussed in more detail with respect to FIG. 3 below.

10 In FIG. 2, the company B 202 starts its workflow K 206 with a plan production task 214 according to its routine schedule. Once management has verified the availability of resources in an approval task 216, then an abstracted view of the two tasks 214 and 216, i.e., a production planning virtual task 218 within workflow L 208, is also considered to be completed.

At this point, a notification 220 is sent to company A 204, which starts a verification task 222, which actually involves company A 204 checking an availability of its production line in task 224, and generating an approval for company B 202 in approval task 226.

Company A 204 then sends a response to company B 202 in response task 228, which is received by company B 202 in a check response task 230. At this point, company B begins a virtual production task 232, which includes a splitting task 234 which conditionally splits the production process into a first widget-producing task 236 and a second widget-producing task 238, or into a third-widget producing task 240 and a fourth widget-producing task 242. Completion of a joining task 244 for joining the widgets then completes the virtual production task 232.

At the same time that company B 202 is performing the production task 232, company A 204 begins its own production task 246, which includes an assembly task 248 and a delivery task 250 for delivery to a different production line inside company A 204.

Once company B 202 finishes its production task 232, it assembles the widgets that have been produced in an assembly task 252, and delivers them in a delivery task 254, which completes a workflow view delivery task 256. Company A 204 then performs a workflow view task 258, and assembles the master product in an assembly task 260, which corresponds to an actual assembly task 262 and an actual quality control task 264.

FIG. 3 is an illustration of a more generic example of the three-tiered workflow model of FIG. 2. In FIG. 3, as in FIG. 2, company B 202 has a private workflow K 302 and a corresponding workflow view L 304. Similarly, company A 204 has a private workflow O 306 and a workflow view P 308.

5 Private workflow K 302 includes a first task 310, a second task 312, a third task 314, a fourth task 316, a fifth task 318, a sixth task 320, a seventh task 322, an eighth task 324, a ninth task 326, and a tenth task 328. The first task 310 and the second task 312 are grouped into a first abstracted task 330 within workflow L 304. The third-eighth (314-324) tasks are grouped into a second abstracted task 332 within workflow L 304, and the ninth task 326 and the tenth task 328 are grouped into a third abstracted task 334 within workflow L 304.

10 Private workflow O 306 includes a first task 336, a second task 338, a third task 340, a fourth task 342, a fifth task 344, and a sixth task 346. The first task 336 and the second task 338 are grouped into a first abstracted task 348 within workflow P 308. The third task 340 and the fourth task 342 are grouped into a second abstracted task 350 within workflow P 308, and the fifth task 344 and the sixth task 346 are grouped into a third abstracted task 352 within workflow P 308.

In FIG. 3, the various workflows may be similar in operation to those shown in FIG. 2. In FIG. 3, however, it is shown explicitly that a collaboration of companies B 202 and A 204 may be expressed as a coalition workflow M 354. In FIG. 3, coalition workflow M 354 is shown to contain a first collaborative task 356, a second collaborative task 358, a fourth collaborative task 360 (a splitting task), a fourth collaborative task 362, a fifth collaborative task 364, a sixth collaborative task 366 (a joining task), and a seventh collaborative task 368. Workflow M 310 may be implemented in a peer-to-peer manner as in FIG. 2, or may be implemented by, or with the help of, a mediating party, as discussed in more detail below.

25 Thus, In FIG. 3, there are six view-activities 330, 332, 334 (in workflow view L 304), and 348, 350, and 352 (in workflow view P 308). The rules for describing how the workflow view activities are to interact are expressed though the coalition workflow M 354, with its activities 356, 358, 362, 364, and 368. The reason that there are a total of six view-activities and only five coalition activities is that one view activity is only intended for monitoring purposes.

30 As shown in FIGS. 2 and 3, each workflow view task in a workflow view corresponds to one or more actual tasks in a partner workflow. Thus, the workflow view(s) provide for

monitoring of their corresponding partner view(s), and an assurance that the partner views are in fact being executed. As discussed in more detail below, this ability may be advantageous over an approach of merely indicating that an interaction between workflows has occurred, or will occur.

5 An analogous way of considering the correlation(s) between workflow views and their corresponding private workflows is to consider the tasks of each in terms of their execution states. In general terms, state changes in one of the actual tasks are required to be made visible to the corresponding virtual task, and vice-versa, as discussed in more detail below.

FIG. 4 is a diagram of an architecture 400 for implementing a three-tier workflow model. In FIG. 4, a first workflow management system 402 includes a variety of elements designed to perform at least the following tasks: implementation of an actual (private) workflow, generation of workflow views (i.e., abstracted or virtual workflows) from the private workflows, and collaboration with an external party such as another workflow management system or workflow mediator to securely implement a coalition workflow.

15 More specifically, the first workflow management system 402 includes a private workflow modeler 404, which supports the lifecycle of private workflow models implemented by the workflow management system 402, such as workflows 206, 210, 302, and 306 in FIGS. 2 and 3.

20 A view modeler 406 is utilized to generate and manipulate workflow views that are abstracted or virtual versions of the actual workflows, such as workflow views 208, 212, 304, and 308 in FIGS. 2 and 3. The view modeler 406 may operate automatically, based on available data, and/or through interaction with a user. Specific techniques for implementing the view modeler 406 are discussed below in Sections II and III.

25 A monitor 408 assists in tracking the execution of private workflows, workflow views, and coalition workflows with respect to one another. Functionality of the monitor 408 is discussed in more detail below.

30 A workflow engine 410 is operable to actually execute the private workflows modeled by the private workflow modeler 404, and to map workflow view states to private workflow states and/or workflow data, as discussed in more detail below. The workflow engine 410 provides relevant information and allows access to workflow views, such that the views can interact with entities outside of the workflow management system 402 as described below. In other words,

the workflow engine 410 executes private workflows internally, and also virtually executes workflow views and ensures the appropriate interdependencies between the two types of workflows.

5 A user agent 412 is a human user's interface to the workflow system 402. The user agent 412 can be, for example, a task list. An application conduit 414 allows the workflow management system 402 to interface with external applications, such as back-office applications like customer relationship management systems, supply chain management, and vending machines, as well as front-office applications, such as a word processor or spreadsheets. Application Conduits 414, generally speaking, extend the reach of workflow management
10 systems to collect and disseminate relevant data.

A private workflow and workflow view repository 416 stores and manages workflow and workflow view models and instances, as well as the relationships between the private workflows/workflow views and models/instances of models.

15 A gateway 418 provides a company's process interface to the outside world. It redirects all ingoing and outgoing process requests, serving as a proxy. It hides internal systems from the outer world, and allows the participation of non process-oriented systems in business processes. The gateway 418 also serves as a firewall against unwanted intrusions, and provides transparent routing services to external parties with respect to the workflow management system 402. The gateway 418 may also be used to convert outgoing message objects from a format used by the
20 internal system 402 to a format that can be understood by an external recipient. The gateway 418 can provide a full log of all services that have been invoked on the systems of an organization.

A security manager 420 handles all security-related aspects of communication for the workflow management system 402. It decrypts incoming messages, and verifies the sender's
25 identity in cooperation with a Certificate Authority 422, using a security technique such as Public Key Infrastructure ("PKI"). In the case of implementing PKI, the security manager 420 may also encrypt outgoing messages with the recipient's public key.

In FIG. 4, a mediator 424 interacts with the first workflow management system 402 and a second workflow management system 426 to implement a coalition workflow. However, as
30 discussed above with respect to FIGS. 2 and 3, and discussed in more detail below, the workflow management system 402 and 426 may also interact directly, in a peer-to-peer environment. In

the second workflow management system 426, it should be understood that the elements associated therewith, i.e., a private workflow modeler 428, a view modeler 430, a monitor 432, an engine 434, a user agent 436, an application conduit(s) 438, a private workflow and workflow view repository 440, a security manager 442, and a gateway 444 all provide functionality corresponding to their similarly-named elements within the first workflow management system 402.

In the mediator 424, a monitor 446 is available for interacting with the monitor 408 and the monitor 432. It should be understood that an availability of monitoring functionality for a particular workflow layer within the three-tier model is determined by the availability of information from the relevant workflow engine. Thus, a workflow monitor (such as monitor 446) that belongs to a coalition will be able to track workflows on the public (coalition) and workflow view layer, whilst a workflow monitor (such as monitor 408 or 432) inside a partner company will, in addition, track the company's respective private workflows and their state transitions.

An eServices Repository 448 is an entity of the mediator 424. It is a catalogue of available eServices and their particular characteristics that are available to the mediator. Generally speaking, eServices are services that can be provided to customers by providers who specialize in those particular services. Such eService are discussed in more detail below, and are particularly useful in the architecture of FIG. 4, in which a particular service may be repetitively required by one or more companies within the coalition workflow.

An instance repository 450 persistently stores information about a current state of execution of coalition workflows. This functionality allows monitoring and exception handling; for example, when one of the communication partners has not received a message and the message needs to be re-sent.

In a mediated environment such as that of FIG. 4, the workflow monitor 446 will be able to query state information about other workflow view instances from the instance repository 450. In a non-mediated environment, in contrast, the workflow monitor 446 is required to collect workflow view instance data from the partners' workflow management systems in order to represent the state of coalition workflow instance.

A message queue 452 can be considered to be a mailbox that acts in close cooperation with the instance repository 450. Specifically, it stores messages for communication partners,

thereby supporting offline scenarios.

Finally with respect to the mediator 446, a security manager 454 interacts with the security managers 420 and 442, and the certificate authority 422, to ensure secure communications between the mediator 424 and the workflow management systems 402 and 426.

5 The architecture 400 of FIG. 4 does not reference or require a particular communication protocol or technology. It may be advantageous, however, to utilize a protocol that is sufficiently expressive to allow for the modelling of messages that result in creation of workflow instances from existing workflow models, and support interaction of workflow instances during their lifecycles. These requirements are being supported by, for example, a workflow Extensible
10 Mark-up Language ("XML") specification developed by the Workflow Management Coalition ("WFMC") and described in the WFMC Technical Report WFMC-TC-1023, "Workflow standard-interoperability-wf-xml binding version 1.1," 2001.

Exemplary techniques for utilizing the architecture 400 of FIG. 4 involve the partners in a coalition agreeing on a particular goal to achieve for modeling in a coalition workflow. Partners
15 may choose those tasks of the coalition workflow that they want to implement by their private systems 402 and 426. Each partner will apply a method such as the method of reduction, discussed below in Section III, to the coalition workflow, in order to understand the required relationships of the partner's tasks in the context of the coalition.

Each partner may then either develop new private workflows, using the method of
20 specialization (discussed in Section II), or re-use existing workflows and connect them with their workflow views through generalization (also discussed in Section II). Once each partner has built their respective workflow views, they may apply the method of expansion (discussed in Section III) on the basis of the coalition workflow definition, in order to add the required synchronizing tasks (e.g., AND-splits and ANDjoins) to their workflow views. These modifications are then
25 propagated back to the view's definition in the private workflow & workflow view repository 416 and 440.

The instantiation of a collaborative workflow may be triggered by either an external event to a workflow view or by the request of one of the partners to their private workflow management system 402, 426. Through the execution, state dependencies between workflow
30 view and corresponding private workflow are updated when changes to states occur, as discussed in more detail below with respect to FIGS. 5-7. Eventually, one private engine, such as engine

410, will start executing a private workflow. Once communication with a partner is required, the gateway 418 will request the security manager 420 to encrypt the message and send it off to the recipient. In a mediated environment such as in FIG. 4, the mediator 424 will decrypt the message with the mediator's private key, encrypt it with the recipient's public key, store it and put it in the message queue 452, and inform the appropriate participant about the new message.

Once the recipient has pulled the message from the message queue 452, the recipient decrypts the message with their own private key and sends the message to the engine 434. The engine 434 takes appropriate action by, for example, starting a new private workflow, or forwarding the message to an already running instance.

The communication partners should be able to identify already-instantiated workflow views in a target workflow management system. For example, a token may be passed along the communication chain that identifies the instance and the type of a coalition workflow. The involved workflow management systems 402, 426 are thus able to instantiate their private workflow objects, and assign them to workflow view objects that participate in the coalition workflow. The coalition workflow instance identifier is assigned to these objects.

Thus, the architecture 400 for implementing the three-tiered workflow model of FIGS. 1-3 provides for flexible, robust and secure interactions between the coalition partners. Workflow views are exposed as interaction points, which can be used to form a collaborative workflow. The inter-enterprise coordination thus builds on a distributed business process model where every partner manages their own part of the overall business process.

Returning to FIGS. 2 and 3, the discussion below describes techniques for joining workflow views into a collaboration workflow using "control flow dependencies," and for joining private workflows to workflow views using "state dependencies." In the following discussion, it is assumed that the private workflows 302 and 306 should remain private and confidential, and remain unchanged.

A control flow dependency, generally speaking, expresses how two or more workflows can interact, through the introduction of synchronizing tasks and/or dependencies. In this approach, a closed-state of a preceding task is connected to an open-state of the following tasks. Route tasks, such as joins and splits, coordinate the control flows of the involved workflows to ensure order preservation of the overall workflow that results from the interaction of the individual workflows. For example, an "AND-split" task splits a process flow into two flows,

where each of the flows must be performed before they can be rejoined at an “AND-join” task. Similarly, an exclusive “OR-split” task splits a process flow into two flows, where only one of the flows must be performed before the flows are rejoined at an exclusive “OR-join” task and allows to proceed.

Control flow dependencies provide a loose coupling between workflows, because they merely pass on a state and workflow-relevant data from one workflow to another once it closes. FIG. 2 provides examples of control flow dependencies, specifically, tasks 220 and 228 can be considered to be “splitting tasks” (i.e., AND splits) while tasks 230 and 258 can be considered to be “joining tasks” (i.e., AND joins). These tasks, as shown in FIG. 2, augment the workflow view tasks 218, 232, 256, 222, 246, and 260.

State dependencies, in contrast to control flow dependencies, provide a very tight coupling between tasks. For example, state dependencies between a workflow view and its associated workflow tasks assure that the workflow view always accurately represents the state of its corresponding private workflow tasks, and that any valid messages that are sent to the workflow view by a third entity are forwarded to the appropriate task in the corresponding private workflow.

FIG. 5 is a Petri-Net representation of state and event information related to a workflow task. In FIG. 5, a circle represents state, while a square represents an event.

In FIG. 5, there is shown an open.notRunning.notStarted (“not_started”) state 502, indicating that the task has been created, but was not started yet. This state may lead to a run event (command) 504, which in turn may lead to an open.running (“running”) state 506, in which the task is executing.

The not_started state 502 may also lead to a terminate event 508, in which a user commands termination of enactment of the task, which leads to closed.terminated (“terminated”) state 510, in which enactment of the task is actually terminated. Somewhat similarly, The not_started state 502 may also lead to an abort event 512, in which an application is aborted, which leads to closed.aborted (“aborted”) state 514, in which enactment of the task is actually aborted.

The running state 506 may lead to a suspend event 516, which leads to a state of temporary suspension of execution referred to as open.notRunning.suspended (“suspended”) 518. The running state 506 may also lead to a completion event (“complete”) 520, which in turn

leads to a completed state 522.

In FIG. 5, every state of a task belongs to one of the following groups: (1) open: the task is being enacted, where the state “open” has subgroups (1a) running: the task is being executed, and (1b) notRunning: the task is temporarily not executing, and the state “notRunning” has the further subgroups (1bI) notStarted: the task has not been started yet, and (1bII) suspended: the task is temporarily not being executed; and (2) closed: enactment of the task has been finished, where the state “closed” has the subgroups (2a) aborted: enactment of the task has been aborted by a user, (2b) completed: enactment of the task has completed normally, and (2c) terminated: the task has been aborted by the system.

In the following discussion, the function “change-state” (“cs”) is a function of a task t , and requests t to change from its current state s_0 into a new state s_1 , denoted as: $cs(s_1) t$. The state transition from s_0 to s_1 is denoted as $s_0 \rightarrow s_1$.

Considering FIG. 3, the workflow K 302 includes the first task k_1 310 and the second task k_2 312. The workflow view (virtual or abstracted workflow) L 304 has corresponding task 330. In the discussion below, tasks k 310, 312 within workflow K 302 generically represent private workflow tasks within a private workflow, and task l 330 generically represents workflow view tasks within a workflow view.

Thus, when task l_1 requests $cs(s_1) k_1$, task k_1 310 performs the following assessment. First, task k_1 310 determines whether the state transition $s_0 \rightarrow s_1$ is valid, i.e. whether it is reflected by the adjacent state transition model (as depicted in FIG. 5) of task k_1 310. If so, then task k_1 310 determines whether all operational resources are available; i.e., whether all required private dependencies are active (or, in the case where task k_1 310 is the first task in workflow K 302, whether the local workflow engine 410, 434 is ready to instantiate workflow K 302). If so, task k_1 310 performs the state transition $s_0 \rightarrow s_1$. In this case, s_1 is now the state of task k_1 310.

Similarly, task l_1 330 performs the following assessment upon receiving from task k_1 310 a request for $cs(s_1) l_1$. First, task l_1 330 determines whether the state transition $s_0 \rightarrow s_1$ is valid. If so, task l_1 330 determines whether all operational resources are available; i.e., whether all required virtual dependencies are active (unless task l_1 330 is the first task in workflow view L 304). If so, task l_1 330 performs the state transition $s_0 \rightarrow s_1$, so that s_1 becomes the state of l_1 .

One approach to performing state mapping is to map between states of task(s) to the state of the corresponding virtual task, and vice versa, as shown in Table 1:

Virtual Task	Tasks
open.running	one open.running AND none (closed.aborted OR closed.terminated)
one.notRunning	one open.notRunning AND none closed
open.notRunning.notStarted	first task open.notRunning.notStarted
open.notRunning.suspended	one open.notRunning.suspended AND none (open.running OR closed.aborted OR closed.terminated)
closed.aborted	one closed.aborted
closed.terminated	one closed.terminated
closed.completed	last task and all others that have been instantiated have been closed.completed

Table 1

However, such an approach may be unable to capture all the semantics of a workflow.

5 For example, there may be a situation in which two tasks are being executed in parallel (e.g., task k4 316 and task 318 k5 in FIG. 3 if task k3 314 was AND-split and task k8 324 was an AND-join), and one of them aborts (i.e., enters the state closed.aborted 514). In this case, aborting one task does not mean that its corresponding virtual task must abort as well. This is in contradiction to when a virtual task receives a request to enter into a particular state, particularly
10 open.notRunning.suspended, closed.aborted, or closed.terminated. In these cases, all corresponding private task instances have to enter the respective states of: open.notRunning.suspended, closed.aborted, and closed.terminated, according to the individual state transition model.

Therefore, another approach to state mapping is to explicitly and individually model
15 relationships between virtual and private task states, while also providing a default in the case of absence of an explicit correlation as suggested in Table 1. This approach adds a layer of flexibility and practicality for dealing with real-world workflows, and allows accurate messaging between a private task and its workflow view task, including when the message(s) originate from an external party (i.e., a member of the coalition).

20 FIG. 6 is a Petri-Net representation illustrating state and event information for two successive tasks in a workflow, relative to their workflow view task. The workflow might be, for example, the workflow K 302 in FIG. 3, and the tasks might be task k1 310 and task k2 312. The workflow view (virtual or abstracted) task would then be task l1 330 within workflow view

L 304.

FIG. 7 is a Petri-Net representation illustrating state and event information for a workflow view task in a workflow view, relative to its private tasks. For example, the workflow view task might be task l1 330, and the private tasks might be task k1 310 and task k2 312.

Generally speaking, as described above, state dependencies express that individual tasks in workflow K 302 and workflow view L 304 should not change their state(s), unless such a state change satisfies rules that describe how states in the two workflows relate.

In FIG. 6, when task k1 310 or task k2 312 enters a state, it notifies task l1 330, and vice versa. Also, each state in workflow view L 304 has a corresponding "tentative state," denoted in FIGS. 6 and 7 as "tstate," such as, for example, "task l1 tRun." These tentative states allow task l1 330 to revert to the original state in which it was before it received an event, in case task k1 310 and/or task k2 312 are unable to execute a particular state change request.

In FIGS. 6 and 7, it is assumed that task k1 310 and task l1 330 are initially in a state not_Started 602 and 702, respectively. Also, messages that originate from task l1 330 are prefixed with "l1" when referred to in task k1 310 and task k2 312, whereas messages that originate from task k1 310 or task k2 312 are prefixed with "k1" or "k2," respectively. Events originating from the coalition are prefixed with "c," e.g., "cRun," while events without any prefix originate from the entity where they are used.

In FIG. 7, task l1 330 receives an event cRun 704 from the coalition, and enters a tentative state tRunning 706. Task l1 330 then passes on an event l1tRun 604 to task k1 310, and task k1 310 then enters a state running 606, and sends an event k1run 708 to task l1 330. Task l1 330 then enters a state running 710. If task k1 310 sends a noCommit event 712 instead, indicating that it was not able to perform the request, then task l1 330 returns to its original not_Started state 702.

If the workflow K 302 is instantiated without coalition request by its own workflow engine 410, then the following exchange of events takes place. First, task k1 310 enters the state running 606 using a request to its workflow engine 410, and sends the event k1run 708 to task l1 330. Task l1 330 then enters the state running 710.

A remainder of states and events in FIGS. 6 and 7 mirror the discussion of FIG. 5 above, in the context of task k1 310, task k2 312, and task l1 330. For example, while running, task k1 310 might receive a suspend command 608 from task l1 330, and enter into a suspended state

610. This state might lead to a terminate message 612 from task l1 330, and thereby a terminated state 614, or to an abort message 616, and thereby to an aborted state 618. Of course, the not_Started state 602 could also lead to either the terminated state 614 or the aborted state 618, as well.

5 The running state 606 might also lead to a complete event 620, which in turn leads to the completed state 622. In this case, task k1 310 is instantiated as complete in event 624, and task k2 312 enters into an open_not_Started state 626. Task k2 312 proceeds as just described with respect to task k1 310, with a run event 628, a running state 630, a suspend event 632 and a suspended state 634, a terminate event 636 and a terminated state 638, an abort event 640 and an
10 aborted state 642, and a complete event 644 and a completed state 646.

 In FIG. 7, the running state 710 may lead to a cSuspend event 714 (i.e., a suspend command from the coalition), which leads to a tSuspended state 716. The tSuspended state may lead to a “no commit” event 718 from either task k1 310 or task k2 312, which would return task l1 330 to the running state 710. The tSuspended state 716 might also lead to a suspend command
15 720 (which could also stem directly from the running state 710) for task k1 310 or task k2 312, which would lead task l1 330 into a suspended state 722.

 The suspended state 722 might lead to a cTerminate event 724, and thereby to a tTerminated state 726. The tTerminated state 726 leads to either an actual termination event 728 from task k1 310 or task k2 312, and thereby to a terminated state 730, or to a “no commit” event
20 732 from task k1 310 or task k2 312, and thereby back to the suspended state 722.

 The suspended state 722 may also lead to a cAbort event 734, and thereby to a tAborted state 736, which in turn leads to either a “no commit” event 738 (and thereby back to the suspended state 722) or to an actual abort event 740 for task k1 310 or task k2 312, with an associated aborted state 742. The suspended state 722 might also lead to a cAbort event 744 and
25 following tAborted state 746, which leads either back to the abort event 740 or to a “no commit” event 748 with respect to task k1 310 or task k2 312 (which in turn leads back to the not_Started state 702. Finally with respect to the suspended state 722, it may also lead back to the cRun event 704.

 The running state 710 also leads to a cTerminate event 750, and then to a tTerminated
30 state 752, which leads to either a “no commit” event 754 (and then back to the running state 710) or to a k1 310 or a k2 312 terminate event 728 that leads to the terminate state 730. The running

state 710 also leads to a cAbort event 756, which results in a tAborted state 758. The tAborted state 758 either leads further to the abort event 740, or to a “no commit” event 760 (and thereby back to the running state 710).

5 Finally with respect to FIG. 7, the running state 710 may lead to a cComplete event 762, which in turn leads to a tCompleted state 764. The tCompleted state 764 leads to either a “no commit” event 766 from task k2 312 (and thereby back to the running state 710), or to a complete event 768 (which may also follow directly from the running state 710, without requiring a message from the coalition), and thus to a final completed state 770.

10 Although task k1 310 and task k2 312 execute in series in FIGS. 6 and 7, a general structure of the Petri-Net of task l1 330 (i.e., FIG. 7) would remain unchanged in the situation where task k1 310 and task k2 312 in parallel. However, the events from the private tasks would be correlated differently. For example, task l1 330 could only complete if both of tasks k1 310 and k2 312 completed.

15 As discussed above, control flow dependencies may be advantageously used to connect workflow view tasks from multiple entities into a single, collaborative workflow. Control flow dependencies allow for a way to connect a closed state of one task to an open state of the next task, in a flexible and autonomous way. In contrast, state dependencies may be more suited to connect a particular workflow view task to its underlying actual workflow task(s), since state dependencies provide for accurate and timely interchanges between tasks and workflow view tasks regarding their respective state changes.

20 In performing the various messaging functionalities between the parties involved in a collaborative workflow, content-based messaging may be used, in which messages are routed on the basis of their content. Additionally, dedicated communications channels can be used for messaging. Messaging may be made persistent by the use of elements such as the message queue 452 in FIG. 4, or similar elements, which need not necessarily be implemented in the context of a mediator.

25 Messages may have various dependencies on (i.e., correlations with) one another, derived from the content of messages or from meta-information external to the message itself, such as the timeframe in which messages have been created or received. There may also be ordering dependencies between messages. These ordering dependencies may express that message 1 must be processed before message 2. For example, an “order confirmation” has to be processed

before the shipment notification can be processed. There may also be causal dependencies between messages. A change order depends on its corresponding order. Messages can be invalidated. Subsequent change order messages invalidate previous change order messages and other causal dependent messages, such as the original order or the shipment notification. Such correlation information may be derived from private workflow(s), and be made visible in a workflow view. Once workflow views are combined into coalition workflows, it can be validated that correlation requirements in the coalition workflow can be satisfied. In this case, “correlators” may be used in place of, or in addition to, the “AND-join” tasks discussed in detail herein. In this case, workflow data flow on an instance level should be considered, along with issues related to data formatting and semantic understanding of data that is to be correlated.

FIG. 8 is a block diagram of a task illustrating the task inputs and outputs types of relevant data. In FIG. 8, a task t 802 manipulates data, where the data reflects real-world information about implementation of the task. For the task t 802, Dti represents input data of task t 802 that task t 802 requires to enter the state running, i.e. to commence operations. Dte represents data that task t 802 exchanges while it is in a state open.running, i.e., while task t 802 is operating to achieve its business objective(s), and Dtr represents output data of task t 802 to some other task when it enters the state closed, i.e., when t ends its operation. The union of task-relevant data from all tasks of a workflow form workflow-relevant data.

The term “union of data,” for example in a database context, generally refers to a combination of results of two or more queries into a single result set consisting of all the rows belonging to all queries in the union. The union of data concept can be usefully applied in the present context as well.

For example, in FIG. 3, considering task k1 310 and task k2 312 in relation to task l1 330, input data of task l1 330 is a subset of, or equal to, the input data of task k1 310, and output data of task l1 330 is a subset of, or equal to, the output data of task k2 312. Thus, exchange data of task l1 330 is a subset of, or equal to, the union of exchange data of task k1 310 or task k2 312. More generically, exchange data of any abstracted task “l” will be a subset of, or equal to, the union of exchange data of tasks “k” associated with the abstracted task..

In the context of collaborative workflows as described above with respect to FIGS. 1-7, the union of exchange data of tasks “k” should be modeled with consciousness of the fact that once a view task “l” is a view task of many tasks “k” that require interaction with the coalition,

coalition partners would not be aware in which order they have to exchange data with task “l.” Thus, there should be a maximum of one task “k” within a workflow K such as workflow K 302 that requires data exchange with the coalition through view task “l.” Of course, tasks “k” would still be capable of exchanging data within their own organisation, assuming workflow K is a private workflow in which details are all known to its owning entity.

Also in the context of collaborative workflows as described above with respect to FIGS. 1-7, interchanges between workflows can be achieved by at least the following two techniques: (1) a commonly-adopted process definition language (meta-model), or (2) commonly-agreed interfaces/message formats. The latter is a partial solution, as it enables invocation semantics (interaction at the business process execution level), while the former allows full interoperability because it enables business processes to interact at the level of any modelling element - as if it were a single organizational business process.

Common process definitions or a common meta-model would require adoption of a common process definition language by workflow vendors, and would allow true interoperability of business processes supported by different workflow engines. However, this goal may not always be easily achievable.

On the other hand, process interoperability standards at an interface layer are more widely and easily supported by industry and workflow vendors. Generally speaking, communication-interoperability between workflow management systems can be realized by, for example, direct interaction of workflow management systems via a set of standardized functions, message-passing between the systems, use of shared data stores (e.g. commonly accessible repositories) by the systems, or bridging of systems using gateways to connect different protocols and formats (as discussed in more detail with respect to gateways 418 and 444 in FIG. 4). These four approaches to communication-interoperability are not necessarily exclusive of one another.

In a mediated environment such as that just described, there is one central participant that is able to route information to the communication partners, which do not have to know each other. Prior knowledge about the mediator is sufficient. All or some communication is routed through the mediator, which decouples the sender and receiver of information and sets the number of individual communication paths at $2n$, where n is the number of participants.

In contrast, in a peer-to-peer (P2P) environment, all communication partners directly

know about each other. They may still be using Internet services, such as the eServices repository 448 or the certificate authority 422. However, all communications are direct between the communication partners. This requires that all the participants agree on a method of interaction. Also, the number of individual communication paths between participants is higher than in a mediated environment, and equal to $(n^2 - n)$.

Mediation has at least two facets: (1) stateless, in which the mediator passes messages from sender to receiver, and (2) stateful mediation, which may be either passive or active. Stateful mediation allows the matching of request and respond messages, and assignment of the messages to the right participant, particularly in scenarios where the participants do not want to know about each other.

In passive stateful mediation, the characteristics of stateless mediation are included, along with the ability to log the interaction(s) in a persistent storage, thereby facilitating monitoring and error handling. In active stateful mediation, the aspects of passive stateful mediation are included, along with an ability to actively drive the partners' interaction by executing a coalition workflow and invoking the communication partner's IT systems to perform their work.

It is possible for a central workflow engine to mediate the interaction of the partners' workflow systems. In this case, the coalition workflow is physically instantiated, which provides the advantage of facilitating monitoring. Specifically, the coalition workflow reflects the states of the involved workflow views, which reflect the states of their corresponding private workflows. A monitoring tool can directly display the coalition's workflow status information, and there is no need to collect monitoring data from the involved work-flow views.

A stateful mediation also may be achieved through stateless mediation plus a set of supporting services, such as a central monitoring service, as opposed to a central workflow engine. In this case, there is no real need for a central state machine to run a coalition workflow, because there are already the individual state machines that execute their respective private workflows.

In a mixed approach, stateless and stateful mediation services are used where required by the communication partners. In such cases, mediation is used for monitoring, persistence of messages and for offline-support, while other information is exchanged directly between the communication partners.

The remainder of Section I is devoted to a discussion of eServices, such as those

implemented in the eService repository 448 in FIG. 4. Generally speaking, as referred to above, eServices are abstractions of business tasks and entire business processes and describe their capabilities and requirements. Therefore, eServices (also known as Web Services) may be well-suited to assist in hiding enterprise-internal systems details from the outside world, while
5 preserving or enabling the systems' capabilities to participate in inter-organizational business processes.

FIG. 9 is a block diagram of an eService 900. In FIG. 9, eService 900 is an entity that provides information on itself through white pages 902, its owning entity through yellow pages 904, its technical requirements, such as invocation parameters and protocols through green pages
10 906, and a description of how to perform complex business transactions step-by-step through process pages 908. Also in eService 900, local information including process logic 910, application logic 912, and data in a database 914 allow the eService to implement its services for consumers.

The following discussion describes relevant metadata required to express eServices, without regard to their provided service and their industrial domain. An eService specification
15 generally allows for human- and machine readability of eServices information.

White pages 902 provide the specifics about an eService in terms of which purpose it serves, based on standard taxonomies. The white pages 902 may include, for example, a human-readable name and description of the eService (with industry-specific terminology), an identifier
20 of the eService, availability information about the eService, and price/payment information about the eService.

Yellow pages 904 provide general information about a provider of eServices. They generally include, for example, the name and address of the business, and a contact person within the business.

Green pages 906 provide information about the specifics of technical interaction with an eService. This information might include, for example, interaction information (e.g., contact
25 information), and an input/output ("I/O") description.

Process pages 908 assist in describing interaction behavior (including technical information) of the eServices, and are thus related in function to the green pages 906. More
30 specifically, simple eServices are instantiated with a set of input attributes, and (at the end of their instance life cycle) deliver an output set of attributes. Complex services are able to interact

as, for example, a workflow is able to communicate with its outside world to require further input data or to deliver intermediate results. To be able to correctly integrate an eService, it is therefore necessary to describe both the needed interactions and an order in which the interactions are required, and process pages 908 assist in this functionality.

5 In describing relevant metadata required to express eServices, various entity-types and attributes may be included in a cross-organizational workflow meta-model. Such a model is sufficient for querying, monitoring and verifying global and local processes, and serves as a blueprint for their evolution and maintenance. The meta-model identifies a common set of attributes that are required for cross-organisational workflows to interact efficiently in
10 cooperation with the above white pages 902, yellow pages 904, and green pages 906.

A first entity in the meta-model, and the most general, is the coalition. The coalition may represent, for example, a virtual enterprise, extended enterprise, or virtual organization. It is formed by a number of members that have agreed to cooperate for a particular period of time towards a common goal. A default method of interactions may be used to describe the technical
15 interaction(s) preferred in the coalition, while security rights describe the partners' rights to add, modify, view, and delete workflows. Table 2 provides information about the coalition entity.

Coalition	
Attribute	Description
List of Members	Members that form the coalition
Validity	The time of the coalition's existence, expressed as start and end date and time
Default Method of Interaction	Technical interaction preferred in the coalition. Can be overwritten by the workflow or activity
Security Rights	Rights to add, modify, delete, and view workflows

Table 2

Workflow is an entity that represents private partner workflows, workflow views and coalition workflows, thus providing a protocol to interact with tasks within these various workflows. Table 3 characterizes information about the workflow entity.

Workflow	
Attribute	Description
Type	{Partner, View, Coalition}
Relationship to other workflow entities	Is view of partner workflow / Is element of coalition workflow
Process start and termination conditions	Conditions under which workflow starts and closes
Security, audit, control data	Permission to start/interact with a workflow
Specification language	Required to interpret the flows, decisions, etc. resolving the semantic integration issues.
Coalitions	Back-reference to the coalitions that this workflow belongs to
Owner	Owner of the workflow
Supporting WfMS	WfMSs that are able to execute this workflow. Dependencies: specification language, underlying organizational model, available resources
Location	Location of the Engine: geographical data.
Activities	List of activities
Default Method of Interaction	Technical interaction preferred in the coalition. Can be overwritten by the workflow or activity
Transition Conditions	Transitions between the workflows activities and subworkflows

Table 3

An activity entity type represents the tasks in a workflow. Besides activity I/O data for an activity, communication requirements, i.e. the messages to be interchanged with the environment during execution time, should also be considered. It should be noted that, even though an activity may be atomic, the underlying implementation may require executing several steps to perform the activity. Table 4 characterizes information about the activity entity.

Activity	
Attribute	Description
Type	subflow, atomic flow, etc.
Pre- and post-conditions	Conditions for activity to commence/finish
Other scheduling constraints	Such as temporal dependencies
Performing Wf-Engine	All engines that are involved in executing this workflow. Required for distributed workflows.
Activity share-ability	(exportable, private/internal only)
Activity input data	Data required by activity at the start of its lifecycle
Activity output data	Data produced by activity at the end of its lifecycle
Activity communication	Emitted and consumed messages with the outside world during the activity's lifecycle. Required to realize more complex protocol interactions.
Ownership	Ownership of the activity
Default Method of Interaction	Technical interaction preferred in the activity. Usually identical to the workflow's default method of interaction. Can be overwritten if activity is performed by external application, or a human
Role	The role that performs the activity

Table 4

A transition condition describes the paths among workflows and activities. The information about them is useful in forming workflow views. With the introduction of the coalition entity above, there can be “coalition-transitions” connecting publicly visible workflows/activities and internal-transitions within the private workflow of the organizations. If there is the need to expose an internal-transition to the coalition because it is part of a coalition-wide JOIN/SPLIT-condition, then this may be made visible by setting a transition share-ability attribute. Table 5 characterizes information about transition conditions.

Transition Conditions	
Attribute	Description
Flow condition	Edge been information source and information sink
Transition share-ability	Exportable/private/internal only

Table 5

The implementation entity describes an implementation of an activity. A separation between activity entity type and implementation entity type is particularly sensible when coalition participants dynamically implement activities, such as in an eMarketplace, where the cross-organisational workflow should stay unchanged, but the binding to a particular implementation should be modified. Table 6 characterizes information about the implementation entity.

Implementation	
Attribute	Description
Execution parameters	Parameters required to execute the implementation
Location or access path	Execution semantics
Workflow	The workflow that implements this implementation
Activity	The activity that implements this implementation

Table 6

A workflow relevant data entity is used by the workflow itself, and influences the transitions between the views. There is no clean separation between application data and workflow relevant data, as the results of the application operation influence the workflow's transitions. A role is the entity in the model that describes the performer of an activity. It reflects an entity in an organization and provides information how to possibly contact the role implementer.

When a service consumer requests an eService from a service provider, the service consumer generally specifies required attributes and their values, and launches a query in an eService repository. The query delivers back to the service consumer a set of services that match the query, and the service consumer then refines the query and selects one or more services.

The services are then bound to the service consumer's business task. When there is a strong requirement on an availability of the eService, then a set of similar eServices would be tentatively bound to a business task as well, so that, at runtime, one of them could be selected according to its availability. The business task of the service consumer can be atomic, or can be
 5 part of a business process that can be represented by a workflow.

At this point, the eServices are invoked, and data is sent from the service consumer to the service provider. Interaction may then occur with the services, and data is interchanged between the consumer and the provider. Once the eServices report their completion, the provider sends required data to the consumer. In this interaction model, a provider may invoke further
 10 eServices from another provider, thus becoming a service consumer.

In the description above, steps can be carried through prior to the start of the service consumer's business process (early binding), or during its execution (late binding of eServices). The binding of an eService to a corresponding business task of the service consumer may be done manually or automatically.

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Section II

Section I above discusses described implementations of cross-organizational, collaborative workflows, in which private workflows, each associated with an individual organization, are represented as abstracted "workflow views." The workflow views are joined
 20 together with their respective workflows using state dependencies, and are joined within the collaborative workflows, using control flow dependencies.

In constructing workflow views from workflows (and vice versa), it would be advantageous to have techniques for doing so in a manner which maintains the state dependencies just referred to, and which does not allow for any inconsistencies between an
 25 operation of the workflow view and its underlying workflow. For example, in a case where two parallel tasks in a workflow must both be completed for the workflow to proceed, it would be inconsistent to have the tasks associated with, respectively, two workflow view tasks in series with one another. Such a situation might result in the case where one of the parallel workflow tasks finishes before the other, thereby authorizing a completion of the first workflow view task
 30 and a corresponding starting of the second workflow view task, even though the second actual task is not yet finished (indeed, may not even be started).

Similarly, it would be advantageous to have techniques for quickly, easily, and reliably adding the control flow dependencies between and among the workflow view tasks within the collaborative workflows.

FIG. 10 is a diagram illustrating operations for modifying one or more workflows. In FIG. 10, a first operation 1002 is generalization, in which a workflow is made more abstract (e.g., when a workflow is converted into a workflow view). A second operation 1004, which is the inverse of generalization, is specialization, in which a workflow is made less abstract, or more specific (e.g., when a workflow view is converted into a workflow).

A third operation 1006 is expansion, in which a workflow is joined with another workflow by an addition of, for example, control flow dependencies including routing and synchronizing tasks. Finally, a fourth operation 1008 is reduction, which is the inverse of expansion and which removes or reduces a collaborative workflow of some type into two or more individual-workflows. Expansion and reduction are discussed in more detail in Section III.

The following discussion of Section II thus describes techniques for transforming an abstraction level of a workflow, i.e., making it more or less abstract, while maintaining state dependencies between the original workflow and the transformed workflow. These techniques may be used in the collaborative workflows discussed above in Section I, but may also be used on their own. For example, a company may want to maintain privacy of its workflow by generating an associated workflow view, even if that workflow view is not necessarily going to be used in a collaborative workflow.

In discussing these and related concepts, the following terminology is used. Workflow W is considered to be a set of tasks t having dependencies d between the tasks, where T is a nonempty set of tasks within the workflow and D is a nonempty set of dependencies between tasks in t . A task t represents the work to be done to achieve some given objectives within a workflow, and can represent both automated and manual tasks. Tasks are performed by assigned processing entities.

Tasks are further classified into three types: activity (A), sub-workflow (SW), and route (R). An activity is atomic and is an implementation of a task. A sub-workflow is a composite task that is a placeholder for another workflow. A route task permits the expression of dependency conditions, and includes the AND-split (AS), AND-join (AJ), XOR-split (XS), and XOR-join (XJ), the functions of which are discussed in more detail below.

A dependency d defines the execution dependency between two objects in a workflow model. By connecting tasks through dependencies, the dependencies may represent the edges of an adjacent digraph, while tasks represent vertices. More specifically, a directed graph or digraph D , is a finite, nonempty set $V(D) = \{v_1, v_2, \dots, v_n\}$ of vertices and a possibly empty set $E(D)$ of ordered pairs of distinct vertices. The elements of $E(D) = \{e_1, e_2, \dots, e_m\}$ are called arcs. The underlying graph of a digraph D is that Graph G obtained from D by replacing all arcs (u, v) or (v, u) by the edge uv . The number of vertices in a digraph D is called its order, which is denoted as $p = \text{order}(D)$ and the number of arcs in D is its size, denoted as $q = \text{size}(D)$. A digraph of order p and size q is called a (p, q) digraph. If (u, v) is an arc of D , then u is said to be adjacent to v and v is adjacent from u . Further, the arc (u, v) is incident from u and incident to v . The outdegree $od(v)$ of a vertex v in a digraph D is the number of vertices adjacent from v and the indegree $id(v)$ of v is the number of vertices adjacent to v . The degree $\text{deg}(v)$ of a vertex v in D is defined by $\text{deg}(v) = od(v) + id(v)$.

If D is a digraph of order p and size q , with $V(D) = \{v_1, v_2, \dots, v_p\}$. Then

$$\sum_{i=1}^p od(v_i) = \sum_{i=1}^p id(v_i) = q \quad \text{Eq. (1)}$$

A walk in D is an alternating sequence $W : v_0, e_1, v_1, e_2, v_2, \dots, v_{n-1}, e_n, v_n$ ($n \geq 0$) of vertices and arcs beginning and ending with a vertex such that $e_i = (v_{i-1}, v_i)$ for each i with $1 \leq i \leq n$. The walk W is a $v_0 - v_n$ walk of length n . A trail is a walk in which no edge is repeated and a path is a walk in which no vertex is repeated. Thus, a path is a trail, but not every trail is a path.

Two vertices u and v in D are connected if D contains a $u-v$ walk. For a vertex v of D , its neighborhood $N(v)$ (or $NG(v)$) is defined by:

$$N(v) = \{u \in V(D) \mid (v, u) \in E(D) \vee (u, v) \in E(D)\} \quad \text{Eq. (2)}$$

The adjacency matrix $D_{p \times p} = [d_{ij}]$ of a (p, q) digraph D is the (p, p) matrix defined by:

$$d_{i,j} = \begin{cases} 1, & \text{if } (v_i, v_j) \in E(D) \\ 0, & \text{otherwise} \end{cases} \quad \text{Eq. (3)}$$

The number of components in a digraph is denoted as $k(D)$. In a connected graph, $k(D) = 1$. A structure S is a subset of a digraph D . It is: $V(S) \subseteq V(D)$ and $E(S) \subseteq E(D)$. An exchange of elements in a matrix D is represented with:

$$d_{i,j} \Leftrightarrow d_{k,l} | i, j, k, l \in N^+ \wedge 1 \leq i, j, k, l \leq d \quad \text{Eq. (4)}$$

FIG. 11 shows a digraph 1100 . In FIG. 11, there is a task m1 1102, a task m2 1104, a task m3 1106, a task m4 1108, a task m5 1110, a task m6 1112, and a task m7 1114. Pairs of the tasks are joined by dependences, including a dependency m1,2 1116 joining task m1 1102 to task m2 1104, a dependency m2,3 1118 joining task m2 1104 to task m3 1106, a dependency m3,4 1120 joining task m3 1106 to task m4 1108, a dependency m3,5 1122 joining task m3 1106 to task m5 1110, a dependency m4,6 1124 joining task m4 1108 to task m6 1112, a dependency m5,6 joining task m5 1110 to task m6 1112, and a dependency m6,7 1128 joining task m6 1112 to task m7 1114.

Using the techniques and notations described above, the digraph 1100 can be represented as an adjacency matrix, as shown in Eq. (5):

$$M = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad \text{Eq. (5)}$$

As should be understood from the above, the matrix M represents the digraph 1100 in that dependency m1,2 1116 is represented as the “1” in the first row, second column of matrix M. Similarly, dependency m2,3 1118 is represented as the “1” in the second row, third column of matrix M. The third row of matrix M has two “1s,” the first, in the third column, representing dependency m3,4 1120, and the second, in the fourth column, representing dependency m3,5 1122. Similar comments apply to dependencies m4,6 1124, m5,6 1126, and m6,7 1128.

A workflow M is well-defined if it satisfies the conditions of workflow, task, and dependency, as defined above, if it includes at least one task, has only one input task and one output task, is connected, and has no task that links to itself. In this case, workflow M can be expressed as in Eq. (6):

$$[M]_{p \times p} \times \begin{bmatrix} m_1 \\ m_2 \\ \vdots \\ m_p \end{bmatrix} \leftarrow \begin{bmatrix} m_1 \\ m_2 \\ \vdots \\ m_p \end{bmatrix}, \text{ where } m_1, m_2, \dots, m_p \in V(M) \text{ and } p = \text{order}(M) \quad \text{Eq. (6)}$$

From Eq. (6), the operator \leftarrow is referred to herein as "precedes," or "the precedes operator," while \times represents a standard matrix multiplication.

In graph terms, the precedes-operator implies that there is a path from a vertex that is

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represented by an element in the matrix situated on the right hand side of the operator,

$$\begin{bmatrix} m_1 \\ m_2 \\ \vdots \\ m_p \end{bmatrix}, \text{ to}$$

a vertex that is represented in the matrix situated on the left hand side of the operator,

$$\begin{bmatrix} m_1 \\ m_2 \\ \vdots \\ m_p \end{bmatrix}.$$

In FIG. 11, if task m3 1106 is of type AS (AND-split), and task m6 1112 is of type AJ (AND-join), then digraph (workflow) 1100 can be represented as shown in Eq. (7):

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$$\begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} m_{1A} \\ m_{2A} \\ m_{3AS} \\ m_{4A} \\ m_{5A} \\ m_{6AJ} \\ m_{7A} \end{bmatrix} \leftarrow \begin{bmatrix} m_{1A} \\ m_{2A} \\ m_{3AS} \\ m_{4A} \\ m_{5A} \\ m_{6AJ} \\ m_{7A} \end{bmatrix} \quad \text{Eq. (7)}$$

By carrying through the matrix multiplication, the following set of precedes relationships is obtained, expressed in Eq. (8):

$$\begin{aligned}
 m2A &\leftarrow m1A \\
 m3AS &\leftarrow m2A \\
 m4A + m5A &\leftarrow m3AS \\
 m6AJ &\leftarrow m4A \\
 m6AJ &\leftarrow m5A \\
 m7A &\leftarrow m6AJ
 \end{aligned}
 \tag{Eq. (8)}$$

5 The expressions having the same left hand side $m6AJ$ can be combined, and the '+' operator may be interpreted as a conjunction. Its operation is defined by the task-type on the right hand side of the equation. In the above cases of $m4A + m5A \leftarrow m3AS$, the '+' operator expresses that $m3AS$ precedes $m4A$ AND $m5A$. In the second case of $m6AJ \leftarrow m4A$ and $m6AJ \leftarrow m5A$, $m4A$ AND $m5A$ precede $m6AJ$. This allows simplification of Eq. (8) to Eq. (9):

$$\begin{aligned}
 m2A &\leftarrow m1A \\
 m3AS &\leftarrow m2A \\
 m4A + m5A &\leftarrow m3AS \\
 m6AJ &\leftarrow m4A + m5A \\
 m7A &\leftarrow m6AJ
 \end{aligned}
 \tag{Eq. (9)}$$

15 Expressions including XOR-splits and XOR-joins can be treated analogously. For example, in the expression $m4A + m5A \leftarrow m3XS$, the '+' operator would be interpreted that $m3XS$ precedes either $m4A$ or $m5A$. In $m6XJ \leftarrow m4A + m5A$, either $m4A$ or $m5A$ precedes $m6XJ$.

Returning to FIG. 10, the operation 1002 of generalization and the operation 1004 of specialization can be described in terms of the above terminology. For example, generalization, as referred to above, serves to make a workflow more generic (or abstract). This process can be thought of as one in which one or more vertices in a workflow are represented by a single vertex in a workflow view. In contrast, specialization makes a workflow more specific, so that at least one vertex in a workflow view is represented by one or more vertices of a workflow.

The following additional terminology is used in the below discussion: $g(K)$ is the generalisation of a workflow K , and $s(K)$ is the specialisation of workflow K . As discussed below, for each specialization of K there exists a generalisation such that $g(s(K)) = K$, and vice versa, $s(g(K)) = K$. In FIG. 3, for example, workflow view L 304 is one possible generalization

of workflow K 302, while workflow K 302 is one possible specialization of workflow L 304. In FIG. 3, the relationships between abstract tasks including task 11 330, task 12 332, or task 13 334 to their corresponding specialized tasks in workflow K 302 are represented by curved connectors.

5 FIG. 12 is an illustration of a specialization operator 1200. More specifically, FIG. 12 illustrates the l-specialization of M, an (m,m) matrix, and N, an (n,n) matrix, where the l-specialization is written as $Ms(l)N = R$, where R is a matrix of size (r, r) with $r = m-l+n$, such that the m_l column of M and the m_l row of M is replaced with n_1, n_2, \dots, n_n rows and columns of N. The elements of $R = Ms(l)N$ are defined such that i is a row index and j is a column index of R, and $i, j \in N^+$, where N^+ is the set of natural positive numbers. Then the elements of R, r_{ij} ,
10 are defined by Eq. 10:

$$m_{i,j} \mid (0 < i < l) \wedge (0 < j \leq l) \quad (1)$$

$$m_{i,j,n+1} \mid (0 < i < l) \wedge (l+n \leq j \leq r) \quad (2)$$

$$m_{i+l,n,j} \mid (l+n \leq i \leq r) \wedge (0 < j \leq l) \quad (3)$$

$$15 \quad r_{i,j} = m_{i+l-n,j,n+1} \mid (l+n.1 \leq i \leq r) \wedge (l+n \leq j \leq r) \quad (4) \quad \text{Eq. (10)}$$

$$n_{i-l+1,j,l+1} \mid (1 \leq i < n+1) \wedge (1 \leq j < n+1) \quad (5)$$

$$m_{l,j} \mid (i = l+n.1) \wedge (1 \leq j \leq l.1) \quad (6)$$

$$0 \mid \text{all other } i, j \quad (7)$$

In Eq. 10, the individual portions labeled (1) – (7) are referred to hereafter as expressions,
20 for example, expression (1) or expression (2).

In FIG. 12, expression (1) is a matrix portion 1202, expression (2) is a matrix portion 1204, expression (3) is a matrix portion 1206, expression (4) is a matrix portion 1208, expression (5) is a matrix portion 1210, expression (6) is a matrix portion 1212, and expression (7) is represented by remaining portions of the specialization operator 1200 being set to the value “0.”

25 Functionally, expressions (1), (2), (3), and (4) serve to copy the matrix M into the matrix R. Expression (5) enters the matrix N as a whole into the matrix R. Expression (6) connects remaining vertices m_i , that were adjacent from m_l , to $n_{i,l}$.

Thus, the specialization operator 1200 serves to link (i.e., insert the curved lines indicating dependencies, as in FIG. 3) one or more workflow tasks within a workflow view represented by matrix M (analogous to workflow view L 304 in FIG. 3) with one or more tasks
30 within matrix N (analogous to workflow K 302 in FIG. 3). As will be shown in more detail

below, such linking, when performed improperly, can lead to inconsistencies between a workflow view and its corresponding workflow, which in turn may lead to failed state dependencies and/or miscommunication between an entity implementing the workflow and other members of a coalition.

5 FIG. 13 is a matrix 1300 illustrating an algorithm for computing specialization. The algorithm is consistent with Eq. (11), defining an intermediate matrix R^* , of size (r^*, r^*) with $r^* = m+n$, and assuming that $i, j \in N^+$, so that Eq. (11) is:

$$m_{i,j} | (0 < i \leq m) \wedge (0 < j \leq m) \quad (1)$$

$$10 \quad n_{i-m, j-m} | (m < i \leq m+n) \wedge (m < j \leq m+n) \quad (2)$$

$$r^*_{i,j} = r^*_{i,l} | (0 < i \leq m) \wedge (j = m+1) \quad (3) \quad \text{Eq. (11)}$$

$$r^*_{i,j} | (i = m+1) \wedge (0 < j \leq m) \quad (4)$$

$$0 \text{ | all other } i, j \quad (5)$$

15 In FIG. 13, expression (1) is a matrix portion 1302, expression (2) is a matrix portion 1304, expression (3) is a matrix portion 1306, expression (4) is a matrix portion 1308, and expression (5) is represented by remaining portions of the matrix 1300 being set to the value "0."

Expression (1) and expression (2) serve to expand M by N at row and column number $(m+1, m+1)$. Expression (3) and expression (4) serve to link from M to N appropriately, and
20 expression (5) serves to remove the row 1 and the column 1 from R^* . The resulting matrix is P of size $(m+n-1, m+n-1)$.

FIG. 14 is an illustration of a generalization operator 1400. For a matrix M that is a (m, m) matrix, the k, l -generalisation is $R = M g(k, l)$, where $Mg(k, l)$ is a matrix, such that the k, \dots, l columns of M are replaced with a single row and column. The elements of R, wherein R
25 is a (r, r) matrix with $r = m+k-l$, are defined below in Eq. 12., wherein i is a row index and j is a column index, and $i, j \in N^+$. Then Eq. (12) is:

$$m_{i,j} \mid (0 < i < k) \wedge (0 < j \leq k) \quad (1)$$

$$m_{i,j-k+1} \mid (0 < i < k) \wedge (k+1 \leq j \leq r) \quad (2)$$

$$r_{i,j} = m_{i-k+1,j} \mid (k+1 \leq i \leq r) \wedge (0 < j \leq k) \quad (3) \quad \text{Eq. (12)}$$

$$m_{i-k+1,j-k+1} \mid (k \leq i \leq r) \wedge (k+1 \leq j \leq r) \quad (4)$$

$$0 \mid (i = k) \wedge (j = k) \quad (5)$$

$$m_{i,j} \mid (i = k) \wedge (0 < j \leq k-1) \quad (6)$$

5

10 In FIG. 14, expression (1) is a matrix portion 1402, expression (2) is a matrix portion 1404, expression (3) is a matrix portion 1406, expression (4) is a matrix portion 1408, expression (5) is represented by remaining portions of the generalization operator 1400 being set to the value "0," and expression (6) is a matrix portion 1410.

Functionally, expressions (1) and (3) copy the respective $m_{i,j}$ from M into R, and link vertices that were formerly adjacent to $m_{i,k}$ to $r_{i,k}$. Expressions (4) and (6) connect the vertices that were adjacent from $m_{l,j}$ to $r_{k,j}$. Expression (2) is only concerned with copying $m_{i,j}$ from M into R, and has no influence on the re-linking of the elements in R.

15

FIG. 15 is a matrix 1500 illustrating an algorithm for computing generalization. The algorithm is consistent with Eq. (12), defining an intermediate matrix R^* , of size (r^*, r^*) with $r^* = m+1$, and assuming that $i, j \in N^+$, so that Eq. (13) is:

20

$$m_{i,j} \mid (0 < i \leq m) \wedge (0 < j \leq m) \quad (1)$$

$$r^*_{i,j} = m_{i,k} \mid (0 < i \leq m) \wedge (j = m+1) \quad (2) \quad \text{Eq. (13)}$$

$$m_{l,j} \mid (i = m+1) \wedge (0 < j \leq m) \quad (3)$$

$$0 \mid (i = m+1) \wedge (j = m+1) \quad (4)$$

25 In FIG. 15, expression (1) is a matrix portion 1502, expression (2) is a matrix portion 1504, expression (3) is a matrix portion 1506, and expression (4) is represented by remaining portions of the matrix 1500 being set to the value "0."

Analogous to matrix 1300 in FIG. 13, it is possible to expand M by 1 row and 1 column at the index $m+1$, with expression (2) copying column k to column $m+1$ and expression (3) copying row l to row $m+1$, and finally removing the rows $1 \dots k$ and the columns $1 \dots k$ from R. which represents all computational steps of expressions (1) to (4) in Eq. (13) prior to the removal of appropriate rows and columns in FIG. 15. A final step in the computation is to remove the

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rows $m_k \dots m_l$ and the columns $m_k \dots m_l$ from R . The resulting matrix is P of size $(m+k-l, m+k-l)$.

As described above, the specialization operator 1200 in FIG. 12 and the generalization operator 1400 in FIG. 14 serve to decrease and increase, respectively, a level of abstraction of a workflow. As pointed out with respect to FIG. 10, these operations are inverses of one another.

As discussed below, these inverse operations can be thought of as one combined operation, referred to as “verticalization.” Using verticalization, an operator can analyze a workflow and determine all feasible groupings (linkings) of tasks within the workflow to form various workflow views, or, conversely, can examine a workflow view to determine all feasible groupings of tasks into an underlying workflow. Similarly, rather than compute all possible groupings, an operator can select possible groupings only for a particular task (or workflow view task).

In understanding the verticalization operation, it should be understood that the specialization operator 1200 in FIG. 12 replaces one vertex, v_l in a first matrix M with n vertices from a second matrix N . Written above as $Ms(l)N$, it can thus be written more generically as:

$Ms(k, l)N$ with $k = 1$. The generalization operator 1400 in FIG. 14, however, replaces $l-k+1$ vertices in M with one vertex. To represent a graph of one single vertex in a matrix requires a matrix of size $(1, 1)$. Therefore, the generalization operator 1400 could also be denoted as $Mg(k, l)N$ with $[N]1 \times 1$, i.e., a 1×1 matrix.

FIG. 16 is an illustration of the verticalization operator 1600. Based on the above similarities between the specialization operator 1200 and the generalization operator 1400, the verticalization operator 1600, or “ v ,” can be written as: $Mv(k, l)N$. In this case, if $k = 1$ and $\text{order}(N) > 1$, then the operator serves to specialize the matrix M , or make M less abstract. For $l > k$ and $\text{order}(N) = 1$, the operator serves to generalize M , or make M more abstract.

More formally, if M is an (m, m) matrix, and N is an (n, n) matrix, then the k, l -verticalisation of M by N is defined such that $Mv(k, l)N$ is a matrix R of size $(m+k-l-1+n, m+k-l-1+n)$, such that the m_k, \dots, m_l columns of M and the m_k, \dots, m_l rows of M are replaced with n_1, n_2, \dots, n_n rows and columns of N . The elements of $R = Mv(k, l)N$ are defined as follows in Eq. (14):

$$m_{i,j} \mid (0 < i < k) \wedge (0 < j \leq k) \quad (1)$$

$$m_{i,j+l+1-k-n} \mid (0 < i < k) \wedge (k+n \leq j \leq r) \quad (2)$$

$$m_{i+l+1-k-n,j} \mid (k+n \leq i \leq r) \wedge (0 < j \leq k) \quad (3)$$

$$r_{i,j} = m_{i+l+1-k-n,j+l+1-k-n} \mid (k+n.1 \leq i \leq r) \wedge (k+n \leq j \leq r) \quad (4) \quad \text{Eq. (14)}$$

$$n_{i-k+1,j-k+1} \mid (k \leq i < n+k) \wedge (k \leq j < n+k) \quad (5)$$

$$m_{l,j} \mid (i = k+n.1) \wedge (1 \leq j \leq k.1) \quad (6)$$

$$0 \mid \text{all other } i, j \quad (7)$$

10 In FIG. 16, expression (1) is a matrix portion 1602, expression (2) is a matrix portion 1604, expression (3) is a matrix portion 1606, expression (4) is a matrix portion 1608, expression (5) is a matrix portion 1610, expression (6) is a matrix portion 1612, and expression (7) is represented by remaining portions of the verticalization operator 1600 being set to the value “0.”

Functionally, expressions (1), (2), (3), and (4) copy M into R. Expression (5) enters N as
15 a whole into R, and expression (6) connects the remaining vertices m_i , that were adjacent from m_l , to n_l .

To derive the specialization operator from v, set $k = 1$. Then, v_s can be shown to be equivalent to the specialization operator s, as defined in Eq. (10). Similarly, to derive the generalization operator from v, set $n = 1$ and $N = [0]1 \times 1$. Then, v_g is can be shown to be
20 equivalent to the generalization operator g as defined in Eq. (12).

Returning to FIG. 3, and considering the above description of the verticalization operator 1600, it can be seen that not all sub-groupings of, for example, workflow K 302 are valid results of verticalization. For example, as shown in more detail below, there are only thirteen sub-
digraphs (i.e., structures or groupings) in workflow K 302 that are valid to be generalized, and
25 they are (1) {k1, k2} (2) {k1, k2, k3, k4, k5, k6, k7, k8}; (3) {k1, k2, k3, k4, k5, k6, k7, k8, k9}; (4) {k1, k2, k3, k4, k5, k6, k7, k8, k9, k10} (note that this grouping represents all of the tasks of workflow K 302, represented as the grouping “K”; (5) {k2, k3, k4, k5, k6, k7, k8}; (6) {k2, k3, k4, k5, k6, k7, k8, k9}; (7) {k2, k3, k4, k5, k6, k7, k8, k9, k10}; (8) {k3, k4, k5, k6, k7, k8}; (9) {k3, k4, k5, k6, k7, k8, k9}; (10) {k3, k4, k5, k6, k7, k8, k9, k10}; (11) {k4, k6}; (12) {k5, k7};
30 (13) {k9, k10}; (14)-(23) individual tasks k1-k10 of workflow K 302, which are regarded as trivial structures, where the set of trivial structures of workflow K 302 is denoted, “ T_K ”. This

operation is denoted as identification of v-structures (“ivs”).

FIG. 17 is a block diagram illustrating a classification scheme for classifying workflow groups. In FIG. 17, a sample workflow L 1702 includes a first task l1 1704, a second task l2 1706, a third task l3 1708, a fourth task l4 1710, a fifth task l5 1712, a sixth task l6 1714, a seventh task l7 1716, an eighth task l8 1718, a ninth task l9 1720, a tenth task l10 1722, an eleventh task l11 1724, and a twelfth task l12 1726.

In classifying v-structures within a workflow, a structure K is considered to be an “atom” if it consists of at least 2 vertices and $ivs(K)$ results only in T_K and K itself. A structure is considered a “molecule” if it consists of more than two vertices. If a structure is a molecule and $ivs(K)$ results only in atoms and trivial structures, then it is considered as first class molecule; while if $ivs(K)$ results to other molecules, then K is considered to be second class molecule. Thus, in FIG. 17, grouping l2, l3 1728, grouping l4, l5 1730, grouping l8, l9 1732, and grouping l10, l11 1734 are atoms. The grouping 1736 of tasks l1 1704 – l6 1714 is a first class molecule, and the grouping 1738 of tasks l7 1716 – l12 1726 is also a first class molecule. Finally, the grouping 1740 of all tasks in workflow L 1702 is a second class molecule.

In FIG. 3, the vertices $\{k3, \dots, k8\}$, i.e., tasks 314-324 in workflow K 302, are represented by one vertex l2 332 in workflow L 304. This corresponds to grouping (8) in the above listing of verticalizable structures of FIG. 3. The XOR-split (task k3 314) and join (task k8 324) and its embraced tasks ($\{k4, \dots, k7\}$, 316-322) are encapsulated.

FIGS. 18-23 provide further examples of how workflow k 302 can be verticalized (generalized). Some of the examples are valid examples of verticalization, while others are invalid, as discussed individually below.

In FIG. 18, vertices $\{k3, \dots, k10\}$, i.e., tasks 314-328 in workflow K 302 are represented by one vertex l2 1802, which is grouping 10 in the above listing of verticalizable structures. In FIG. 19, tasks 310, 312, 314, 324, 326, and 328 are represented by corresponding individual tasks 1902, 1904, 1906, 1908, 1910, and 1912, respectively. Tasks 316 and 320, are represented by one single vertex, 1914 (grouping 11 above), and tasks 318 and 322 are represented by task 1916 (grouping 12 above).

In FIG. 20A, tasks 310, 312, 314a (which is an AND-split, rather than the XOR split 314 of FIG. 3), 316, and 318 are grouped into one task l1 2002a. Similarly, tasks 320, 322, 324a (which is an AND join, as opposed to the XOR join 324 in FIG. 3), 326, and 328 are grouped

into one task l2 2004a.

In FIG. 20A, the task l1 2002a is ambiguous, because, with regards to the execution of workflow K 302, it would be possible for task k7 322 to start while task k4 316 and, due to their dependency task l1 2002a, are still in progress, or even aborted. Since task k7 322 is represented by task l2 2004a, task l2 2004a would start before task l1 2002a is completed. This course of events contradicts the “AND” nature of split 314a, and violates fundamental rules in workflow, and is therefore invalid.

In FIG. 20B, tasks 310, 312, 314, 316, and 318 are grouped into one task l1 2002b. Similarly, tasks 320, 322, 324, 326, and 328 are grouped into one task l2 2004b.

In FIG. 20B, it would be necessary to analyze workflow K 302 sufficiently to be sure that either tasks k4,6 316,320 or tasks k5,7 318, 322 are executed, which would not necessarily be true.

In FIG. 21, a task l1 2102 includes tasks 310, 312, and 314, while a task l2 2104 includes tasks 316, 318, 320, 322, 324, 326, and 328. In FIG. 22, a task l1 2202 includes tasks 310, 312, and 314, a task l2 2204 includes tasks 316 and 320, a task l3 2206 includes tasks 318 and 322, and a task l4 2208 includes tasks 324, 326, and 328. In FIG. 23, a task l1 2302 includes tasks 310, 312, and 314, a task l2 2304 includes tasks 316, 318, 320, and 322, and a task 2306 includes tasks 324, 326, and 328.

In FIGS. 21-23, the abstracted workflows do not guarantee that their underlying workflows will be properly executed, do not match an operation of the verticalization operator 1600, and/or violate one or more of the corresponding rules for verticalization set forth below.

One such rule that follows from the verticalization operator 1600 is that when a vertex is being specialised, the specialising vertices should act vertex-type-compliant. In other words, a set of vertices “L” that specialize a vertex (or vertices) “k” have to behave like the task type(s) of k. If k is of type AS, then L has to behave like an AND-split, which occurs when L has the identical number of outgoing arcs as k (which are all being used). Analogously, if k is of type XS, then L has to behave like an XOR-split, which occurs when it has the identical number of outgoing arcs as k (where only one is being used). Analogous consideration are applicable to the vertex-types of AND-joins and XOR-joins. Activity and sub-workflow have exactly one incoming and one outgoing arc.

This consideration also applies for the operation of generalization. Here, a group of

vertices L has to be formed such that it behaves like one atomic vertex k .

FIG. 24 is a flowchart 2400 describing an algorithm to compute v -structures. More specifically, the algorithm (referred to as “Kivs”) allows computation of all v -structures within a digraph K , thereby returning $V(B_n)$, i.e. the set of vertices for any identified v -structure B_n . For the following considerations, v_k and v_l are two vertices in K .

In FIG. 24, it is first determined if v_k is not equal to v_l , i.e., that at least two vertices are being considered (2402). If so, then it is determined whether a path between v_k and v_l exists (2404). If so, then it is determined whether the indegree (id) of v_k is less than or equal to one, and whether the outdegree (od) of v_l is less than or equal to one (2406). In other words, it is determined whether the first vertex v_k of the group has no more than one incoming dependency (e.g., an activity task, but not an XOR join route task), and whether the last vertex v_l has no more than one outgoing dependency (e.g., an activity task, but not an AND split route task).

If this condition is met, then all vertices in the $v_k - v_l$ path are determined and stored in a list “B” (2408). Afterwards, it is determined whether any vertex v_i in B is adjacent to any other vertex v_j not in B, and whether any vertex v_i in B is incident from any other vertex v_j not in B (2410). In other words, no vertex in B should have a dependency from or to another vertex not in B (other than the incoming/outgoing dependencies of v_k, v_l). If there is such a dependency, then the list B is invalid (2412). Otherwise, the list B is added to a list “R” of valid structures (if the resulting structure is atomic, it may be replaced by a single vertex).

Afterwards (or if the indegree/outdegree of v_k, v_l was determined to be greater than one), then v_l is incremented (2418). If this incrementing causes the order of v_l to be less than or equal to the order of the entire digraph (workflow) k , then the above process is repeated on the new path, beginning with a checking of the indegree/outdegree of the new path (2406).

Afterwards, then v_k is incremented (2420), and, if v_k is less than or equal to an order of the digraph (workflow) k , then the process repeats from the beginning (2402). Otherwise, the process is finished, and the structures in list R are ordered according to their order (increasing); also, all first class molecules in R are replaced with a single vertex (2424).

Using the above algorithm, in a sequence of length n , $[(n^2+n)/2]$ v -structures are obtained containing at least two vertices, or $[(n^2-n)/2]$ v -structures including n trivial structures. the identification of v -structures will be a core functionality of a

Although the above algorithm is capable of calculating all v -structures in a workflow,